Learning an inverse model for vocal production: toward a bio-inspired model

Silvia Pagliarini, Xavier Hinaut, Arthur Leblois

Learning an inverse model for vocal production: toward a bio-inspired model

6th European Birdsong Meeting, April 12-13, 2018, Odense, Denmark

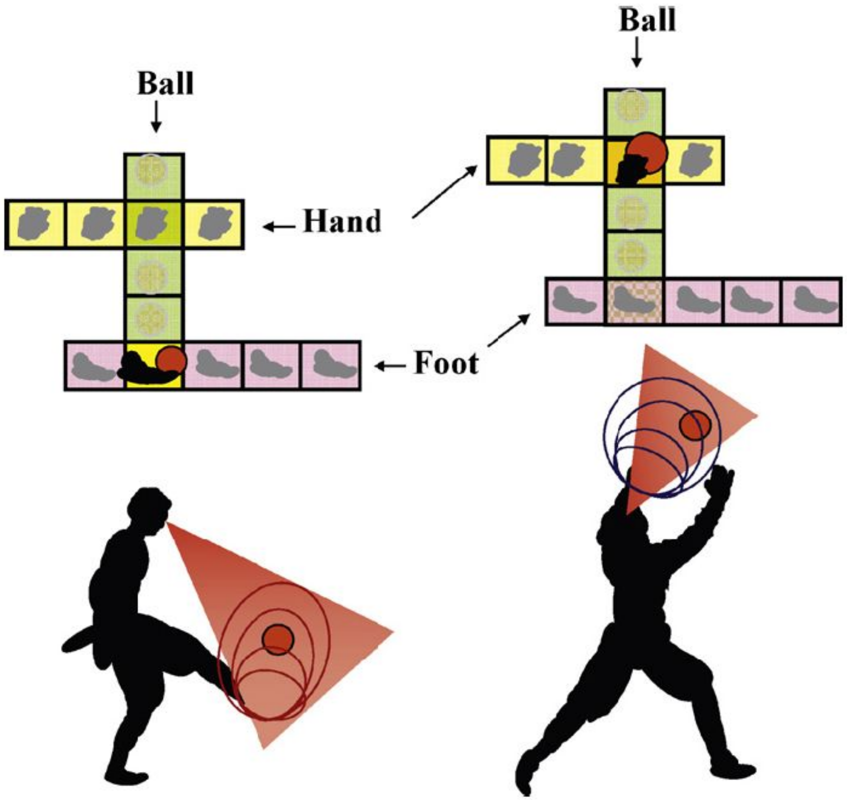
Silvia Pagliarini
(with Xavier Hinaut and Arthur Leblois)
INRIA Bordeaux Sud-Ouest, Institut des Maladies Neurodégénératives, Université de Bordeaux, FR

WHAT IS SENSORIMOTOR LEARNING?

Control problem which maps a sensory input into a motor output

Basic components:

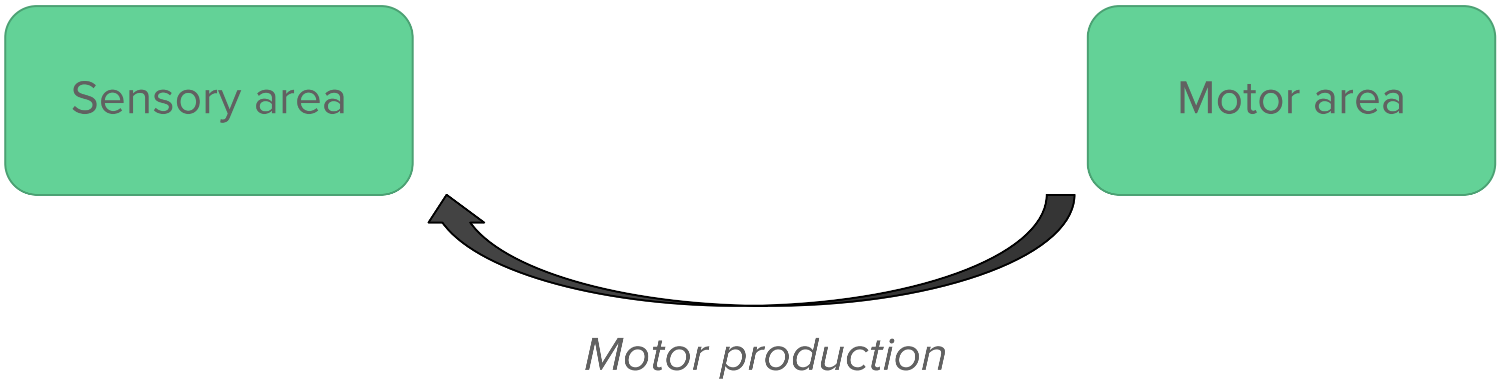
- Input: sensory stimulus
- Output: reproduction of the stimulus



Da Cunha et al., 2010

LEARNING BY IMITATION AND INVERSE MODEL

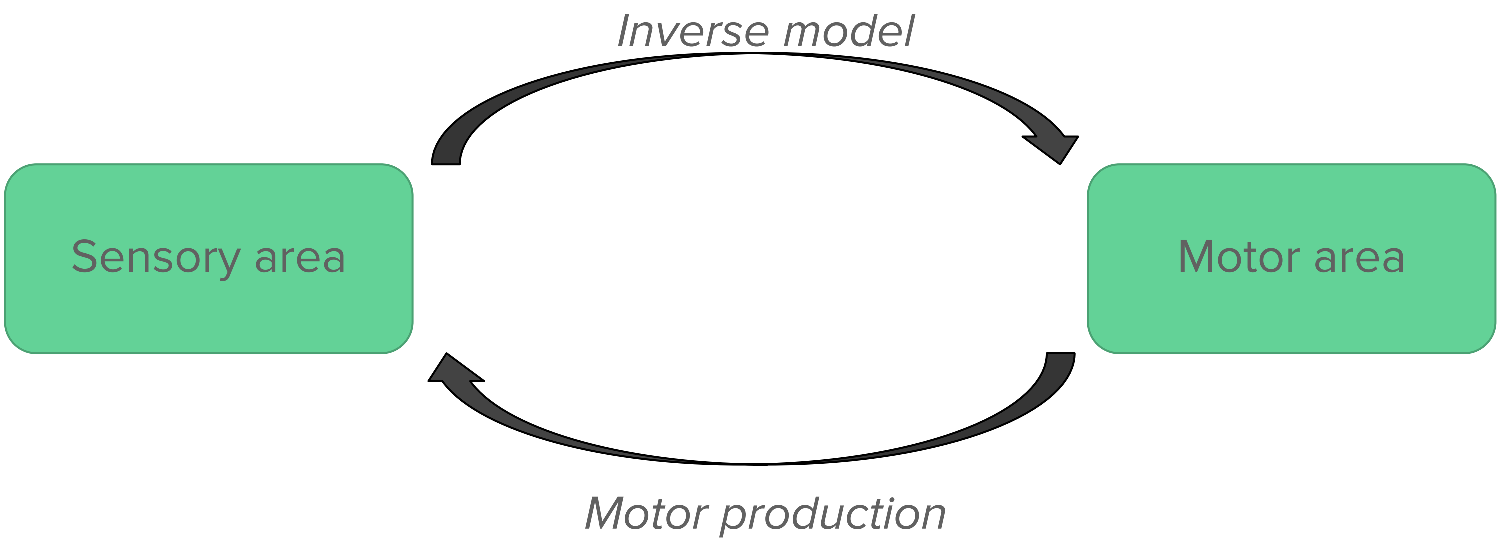
Imitation: learning from a tutor using a feedback guided error



LEARNING BY IMITATION AND INVERSE MODEL

Imitation: learning from a tutor using a feedback guided error

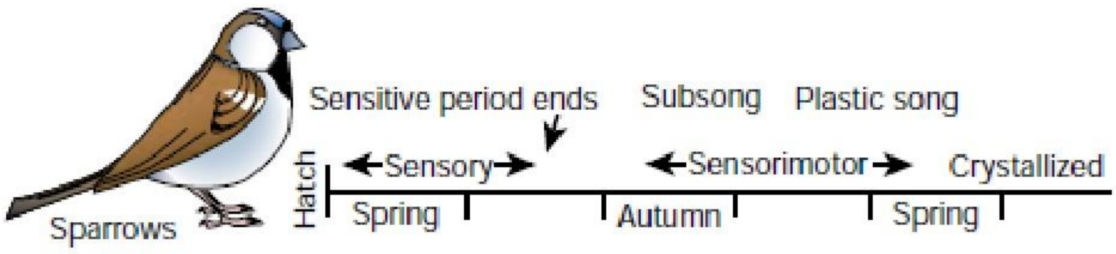
Inverse model: the aim is to transform a sensory stimulus into the corresponding motor command



A BIOLOGICAL EXAMPLE: SONG LEARNING IN BIRDS

- Comparable learning mechanisms and behavior

Sensory → Subsong (Babbling) → Plastic song → Crystallization

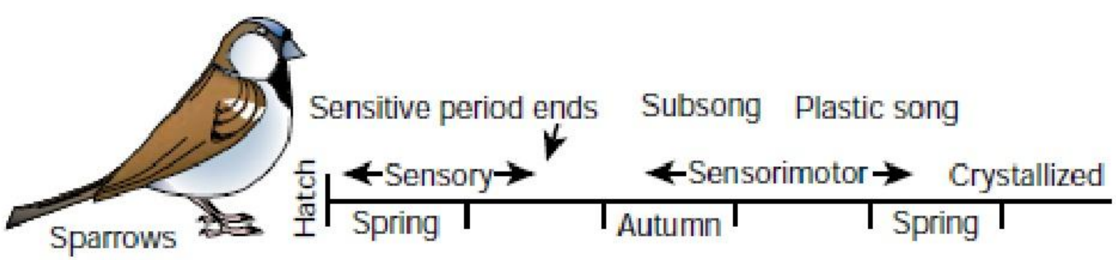


Brainard and Doupe, 2002

A BIOLOGICAL EXAMPLE: SONG LEARNING IN BIRDS

- Comparable learning mechanisms and behavior

Sensory → Subsong (Babbling) → Plastic song → Crystallization

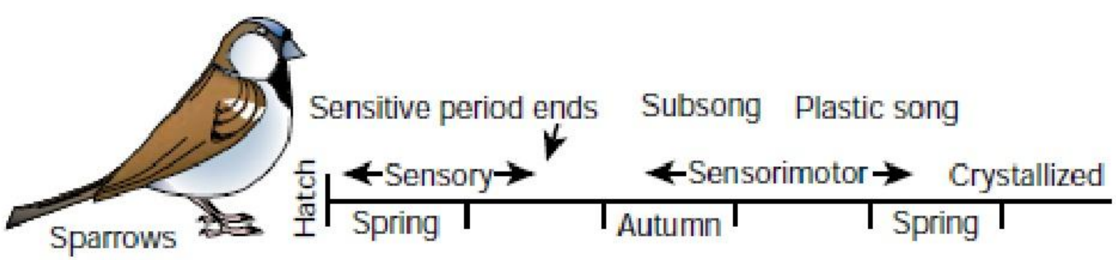


Brainard and Doupe, 2002

A BIOLOGICAL EXAMPLE: SONG LEARNING IN BIRDS

- Comparable learning mechanisms and behavior

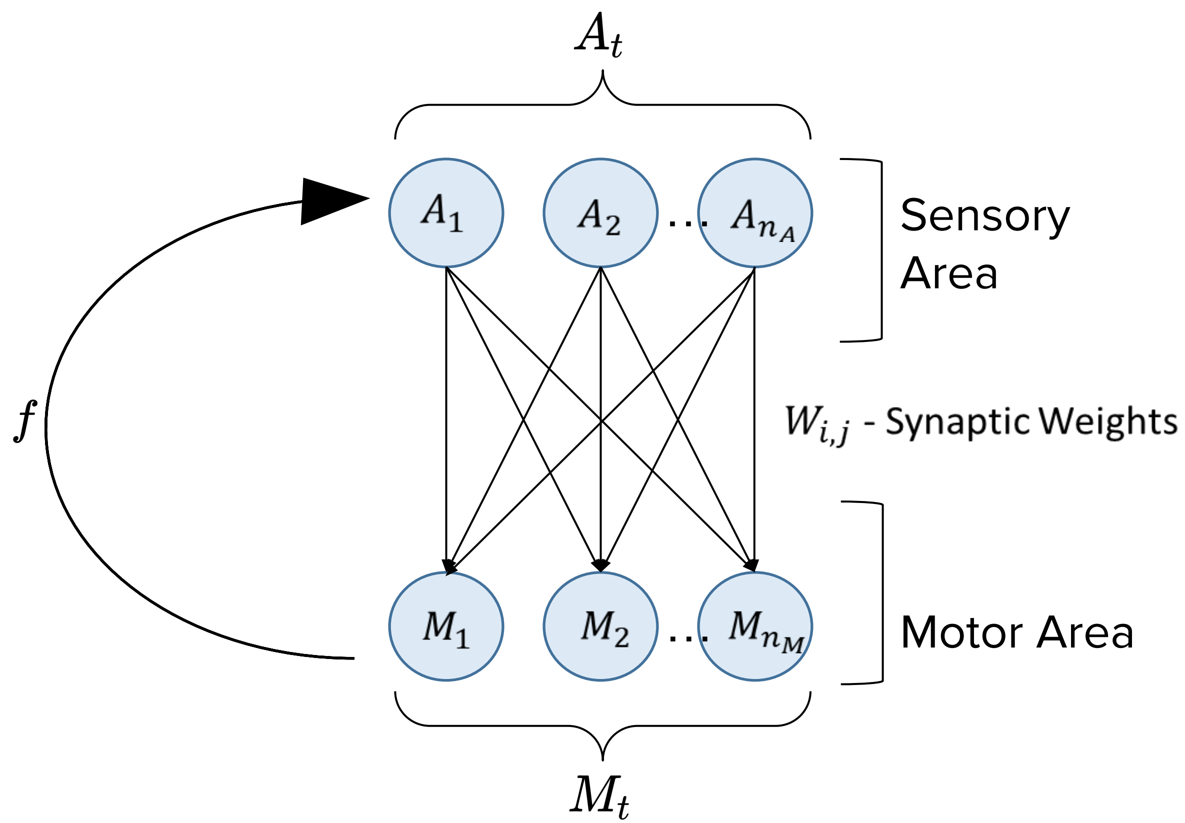
Sensory → **Subsong (Babbling)** → Plastic song → Crystallization



Brainard and Doupe, 2002

LEARNING AN INVERSE MODEL

Synaptic weights $W_{t=t_0}$ initially weak

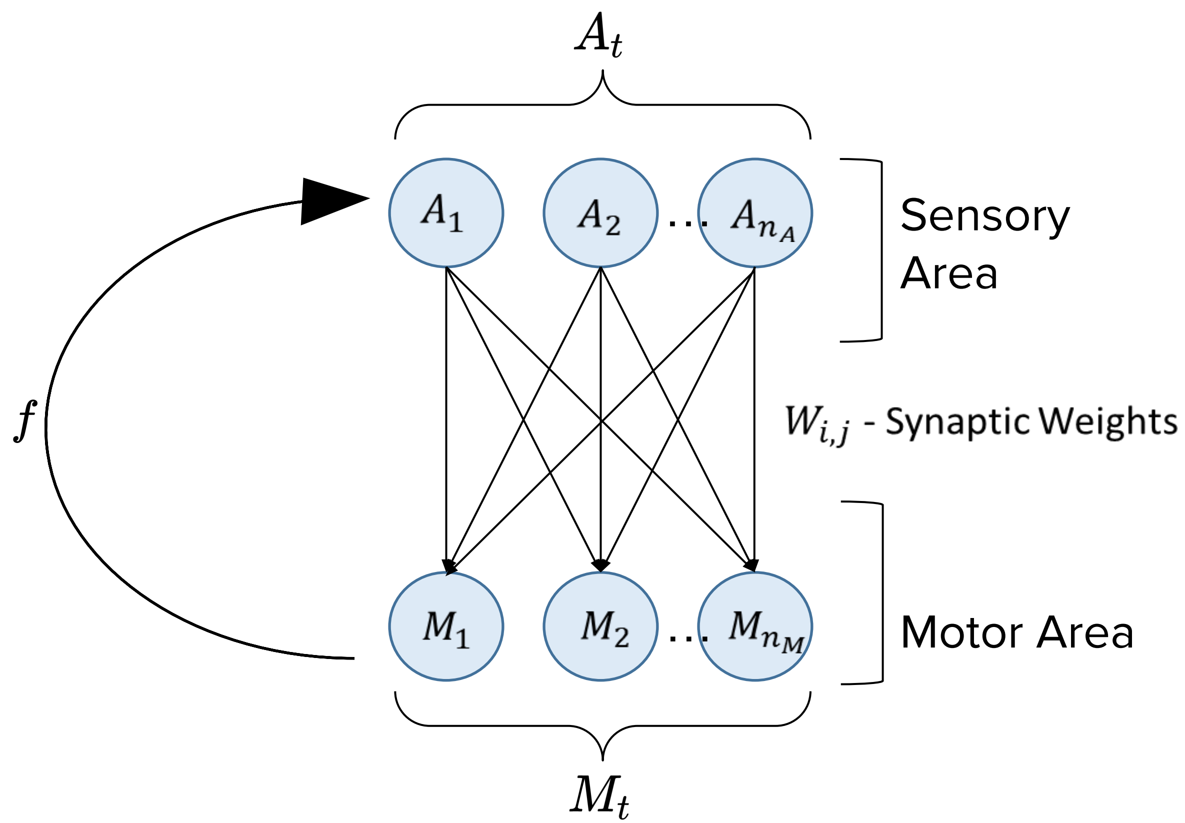


LEARNING AN INVERSE MODEL

Synaptic weights $W_{t=t_0}$ initially weak

At each time t :

- $A_t = f(M_t)$



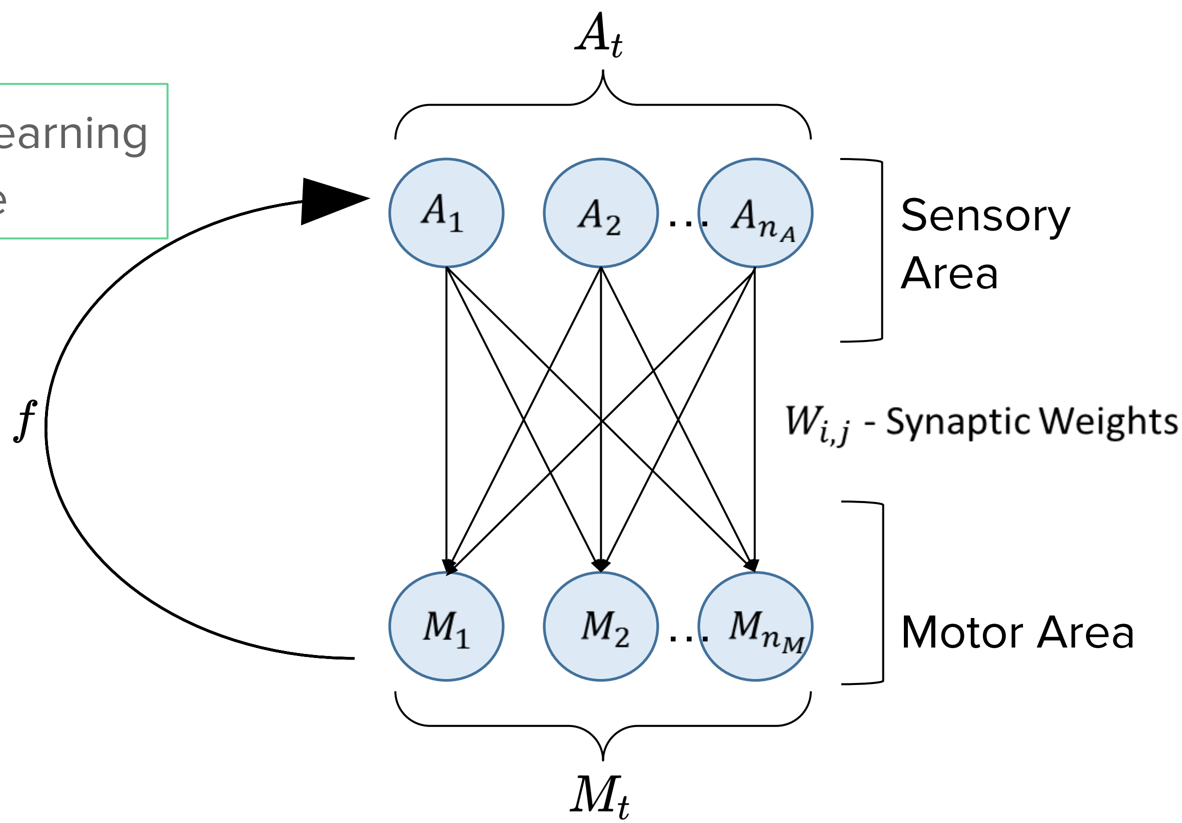
LEARNING AN INVERSE MODEL

Synaptic weights $W_{t=t_0}$ initially weak

At each time t :

- $A_t = f(M_t)$
- $\Delta W_t \propto \eta M_t A_t$

Hebbian learning rule



η : learning rate

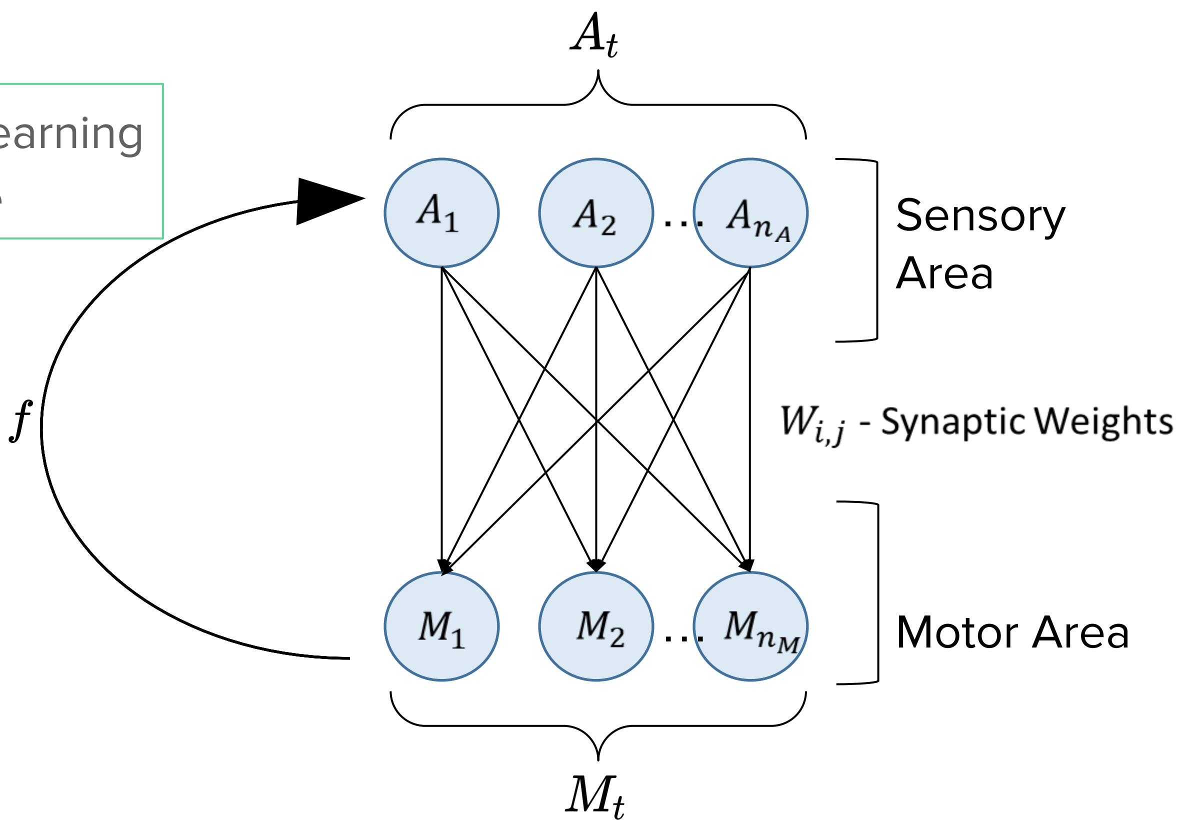
LEARNING AN INVERSE MODEL

Synaptic weights $W_{t=t_0}$ initially weak

At each time t :

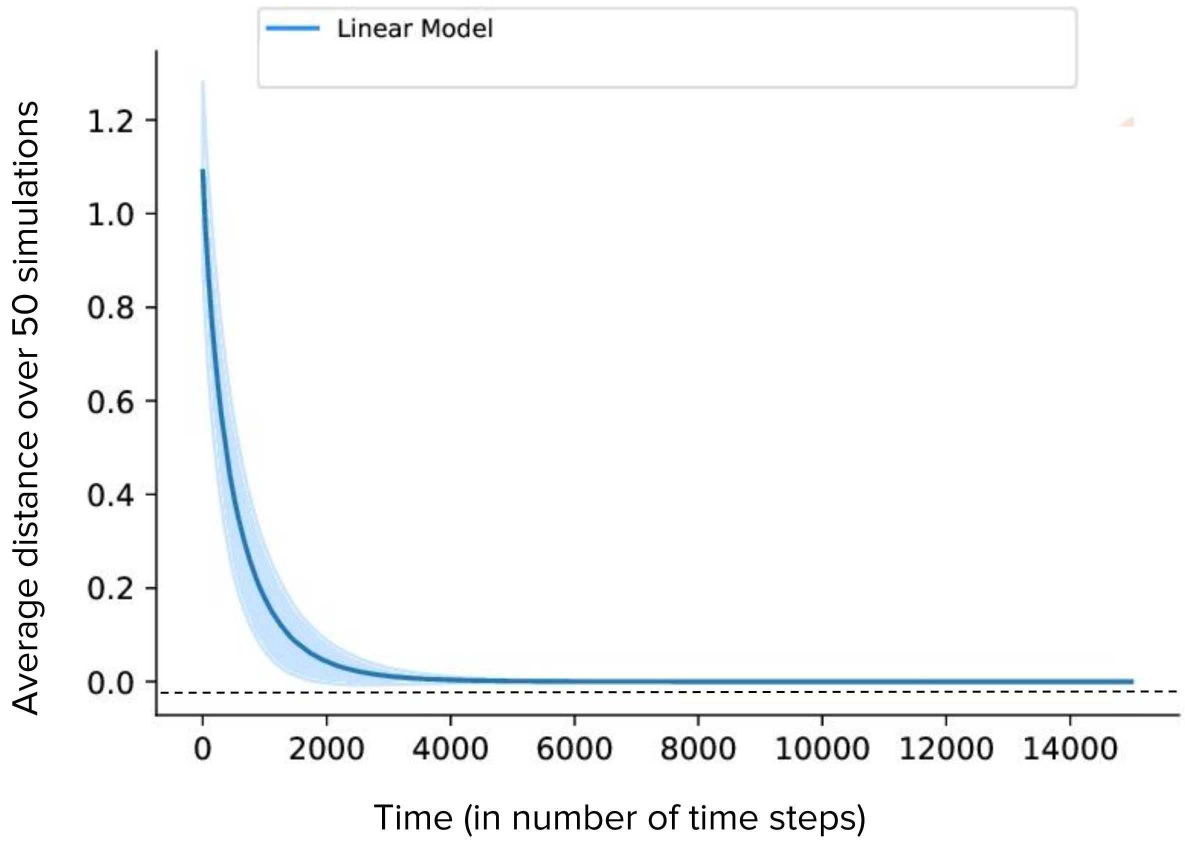
- $A_t = f(M_t)$
- $\Delta W_t \propto \eta M_t A_t$
- $W_t = W_{t-1} + \Delta W_t$

Hebbian learning rule



η : learning rate

HAHNLOSER-GANGULI THEORETICAL MODEL

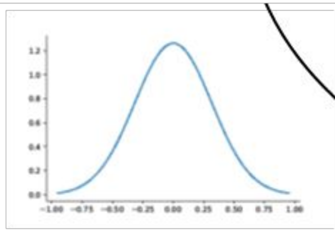


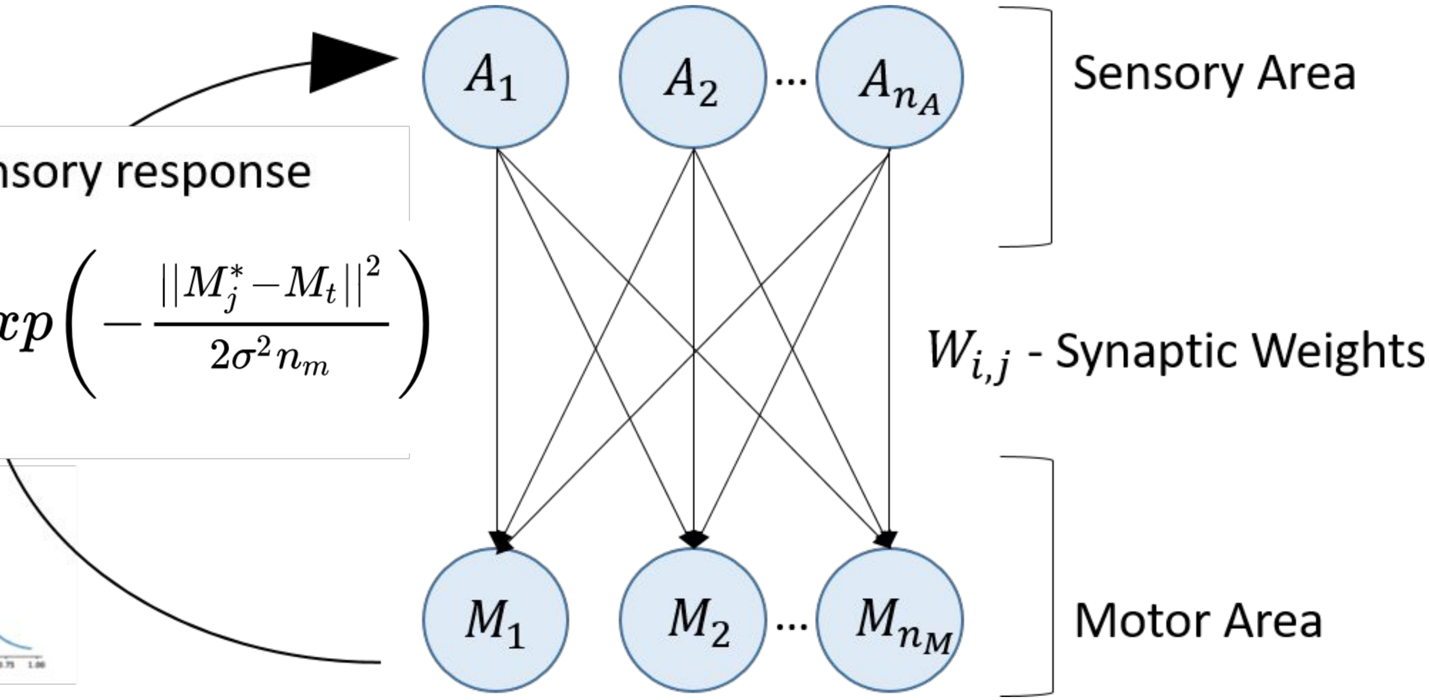
$$\Delta W_t = \eta(M_t - W_{t-1} A_t) A_t^T$$

NONLINEAR MODEL INTRODUCTION

Selective sensory response

$$A_{j,t} = A_0 exp\left(-\frac{||M_j^* - M_t||^2}{2\sigma^2 n_m}\right)$$



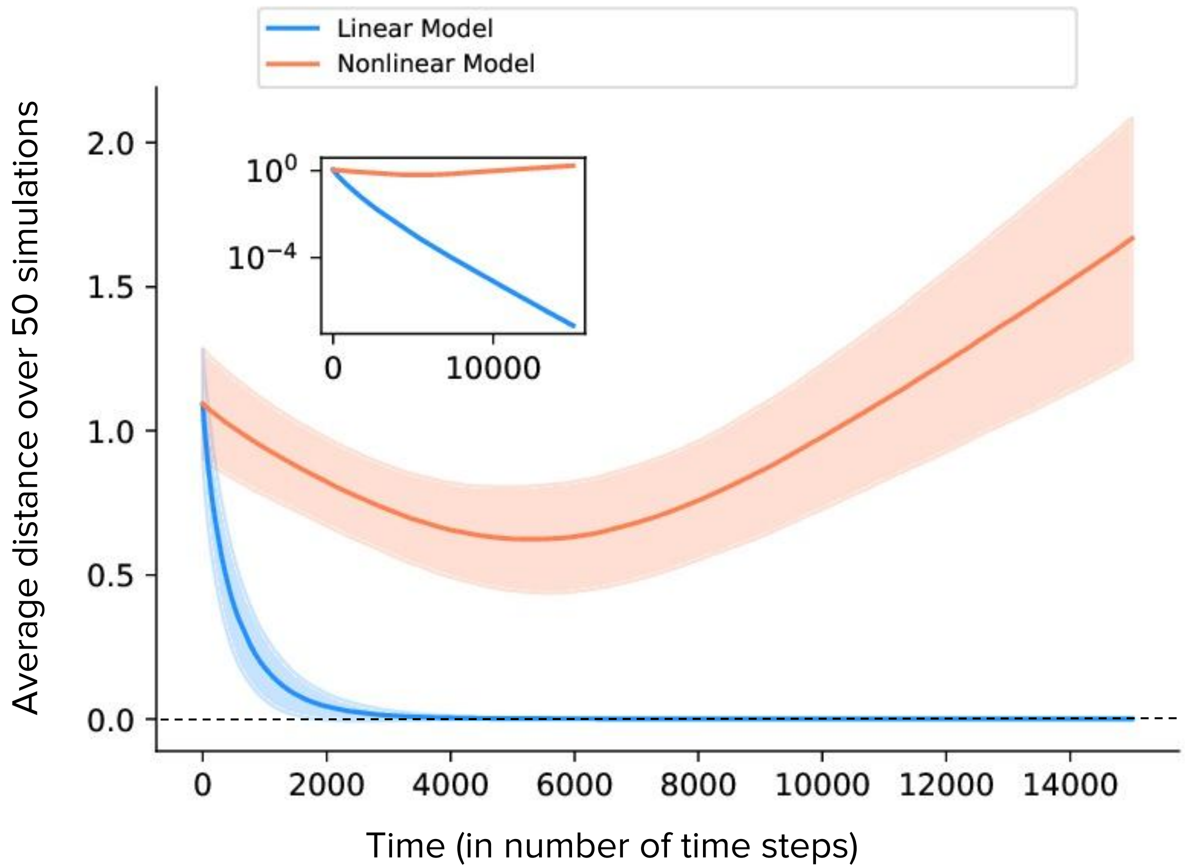


M^* : target motor pattern

σ : tuning selectivity width

$||M_j^* - M_t||^2$ represents the distance between the target and the random exploration

GANGULI-HAHNLOSER MODEL



$$\Delta W_t = \eta(M_t - W_{t-1}A_t)A_t^T$$

NORMALIZATION

Synaptic weights have a maximal value, related to the number of synaptic receptors one neuron is able to produce.

NORMALIZATION

Synaptic weights have a maximal value, related to the number of synaptic receptors one neuron is able to produce.

- Maximal weights normalization $W_{i,j} = \frac{W_{i,j}}{<W>_{col}}$

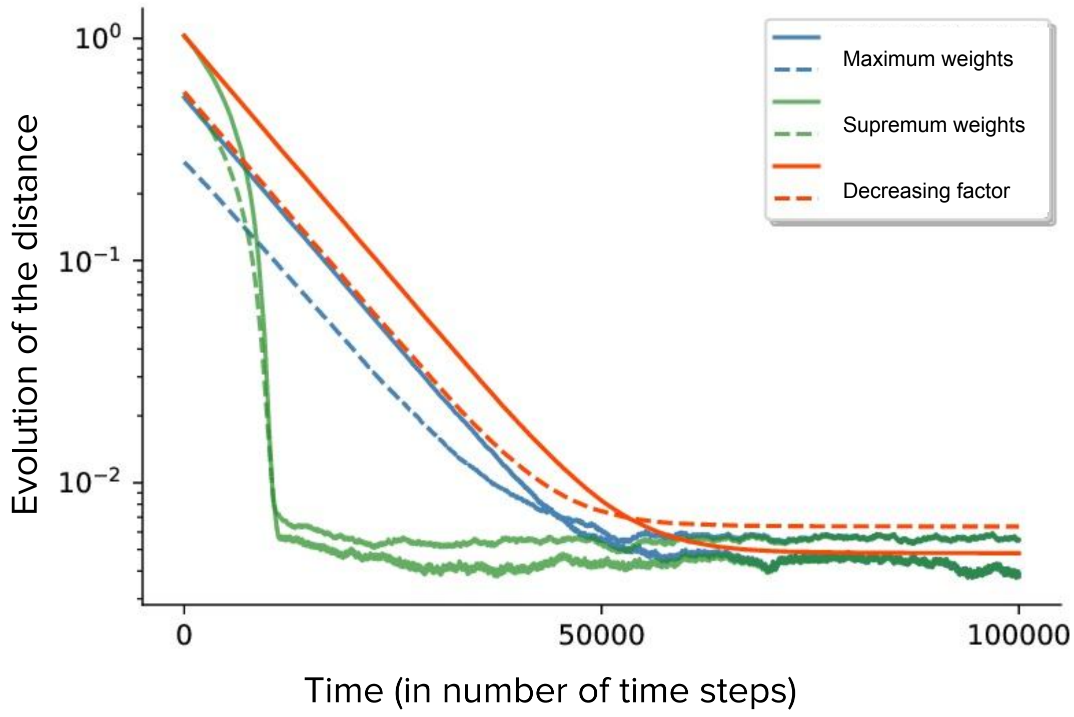
- Supremum weights normalization $W_{i,j} = \begin{cases} W_{i,j} & if \quad <W>_{col} < 1 \\ \frac{W_{i,j}}{<W>_{col}} & otherwise \end{cases}$

NORMALIZATION

Synaptic weights have a maximal value, related to the number of synaptic receptors one neuron is able to produce.

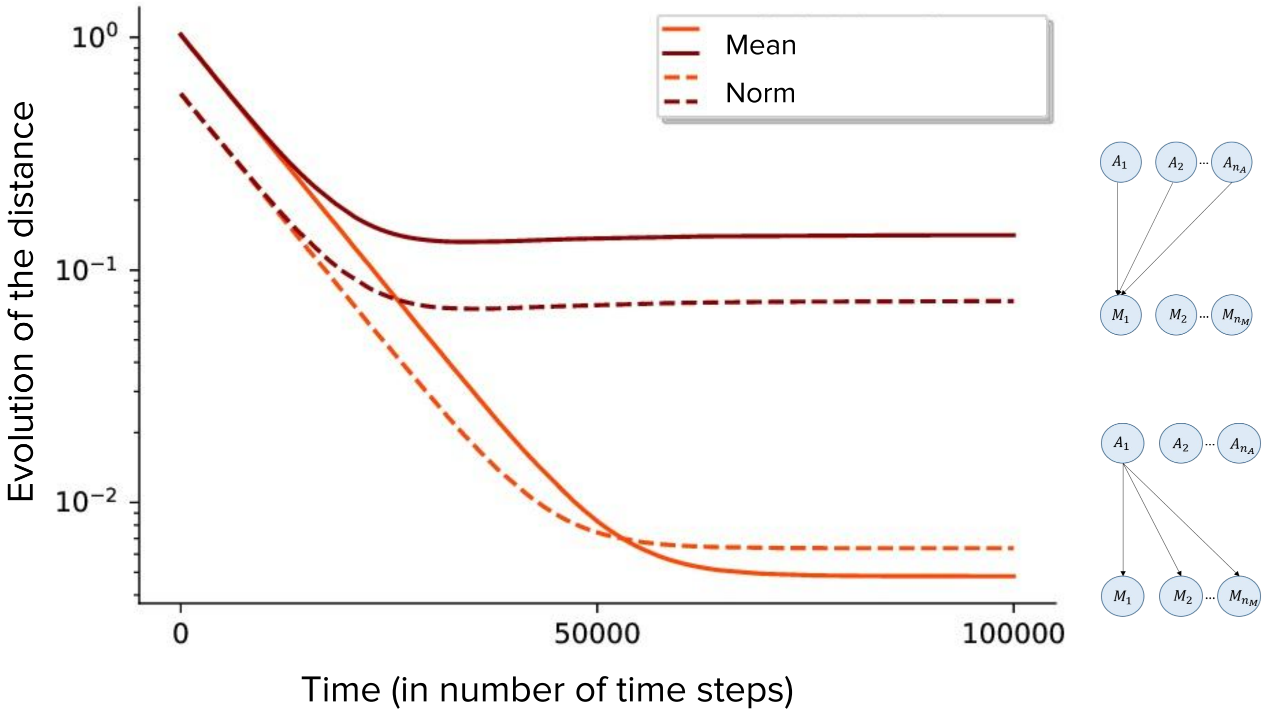
- Maximal weights normalization $W_{i,j} = \frac{W_{i,j}}{<W>_{col}}$
- Supremum weights normalization $W_{i,j} = \begin{cases} W_{i,j} & if \quad < W >_{col} < 1 \\ \frac{W_{i,j}}{<W>_{col}} & otherwise \end{cases}$
- Decreasing factor normalization $\Delta W_{i,j} = \eta M_t A_t \left(1 - < W >_{col}\right)$

NORMALIZED INVERSE MODEL



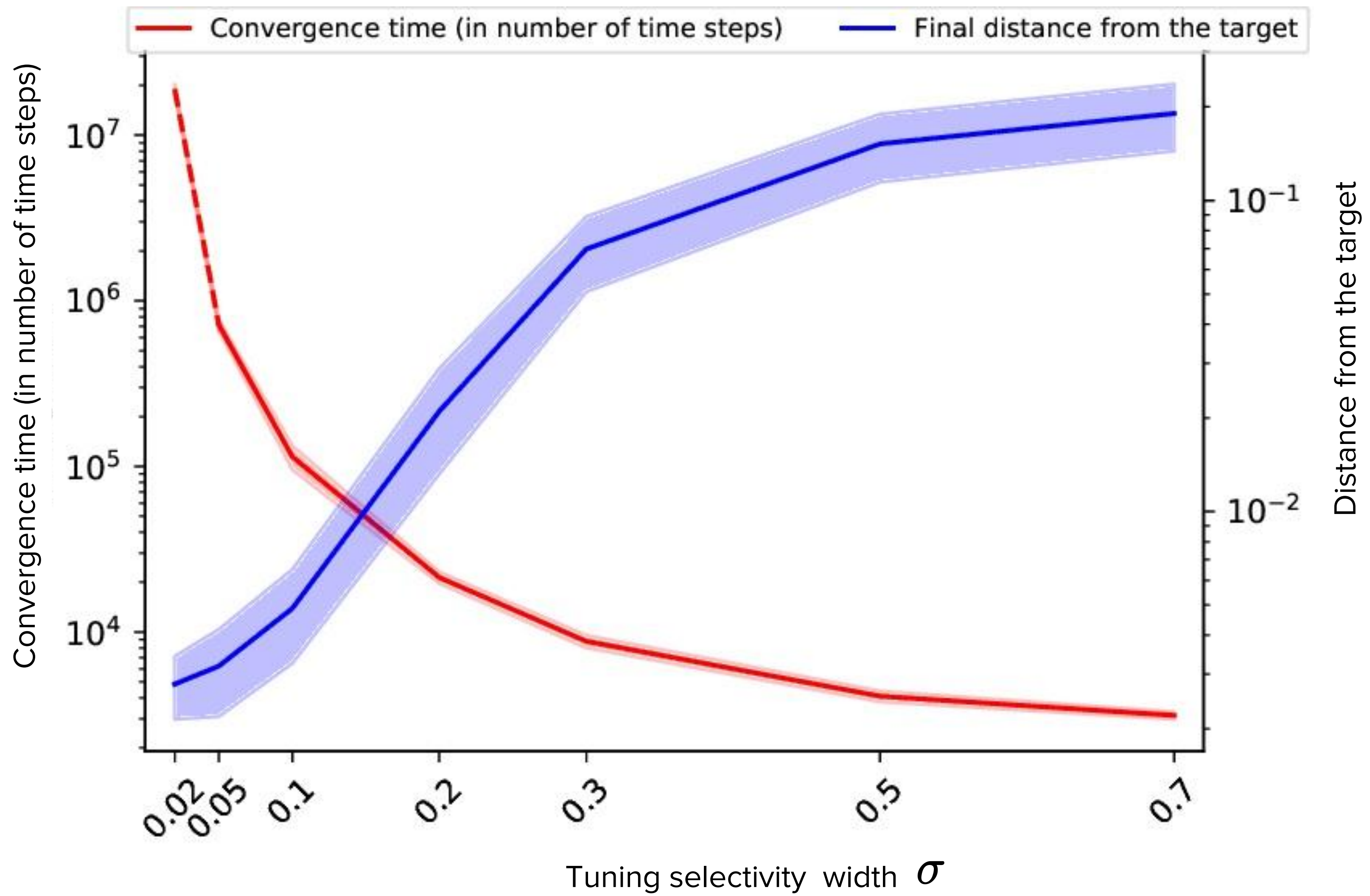
Normalization applied over the auditory neurons

NORMALIZED INVERSE MODEL

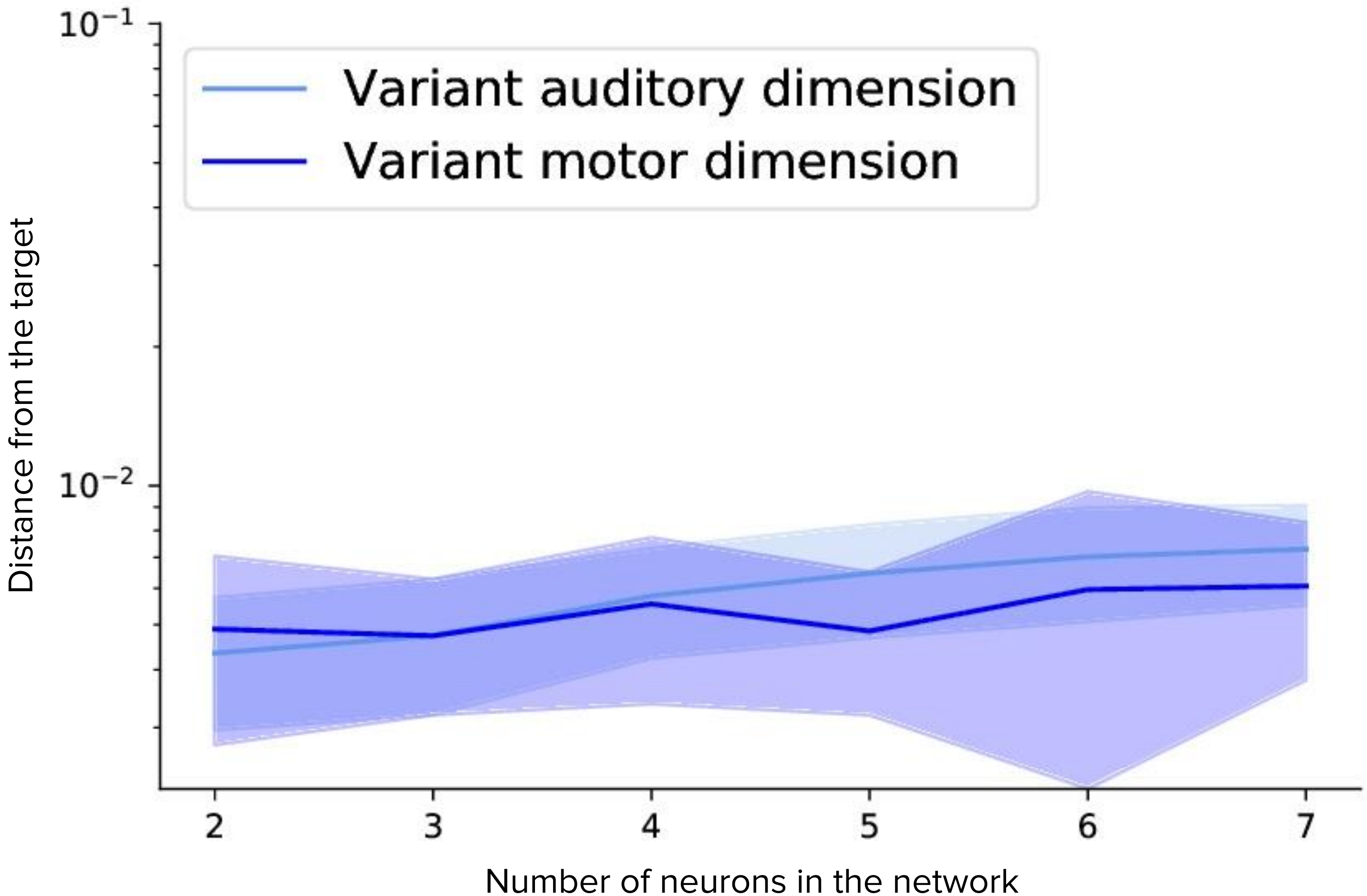


$$\Delta W_{i,j} = \eta M_t A_t \left(1 - < W >_{col} \right)$$

AUDITORY SELECTIVITY EFFECT

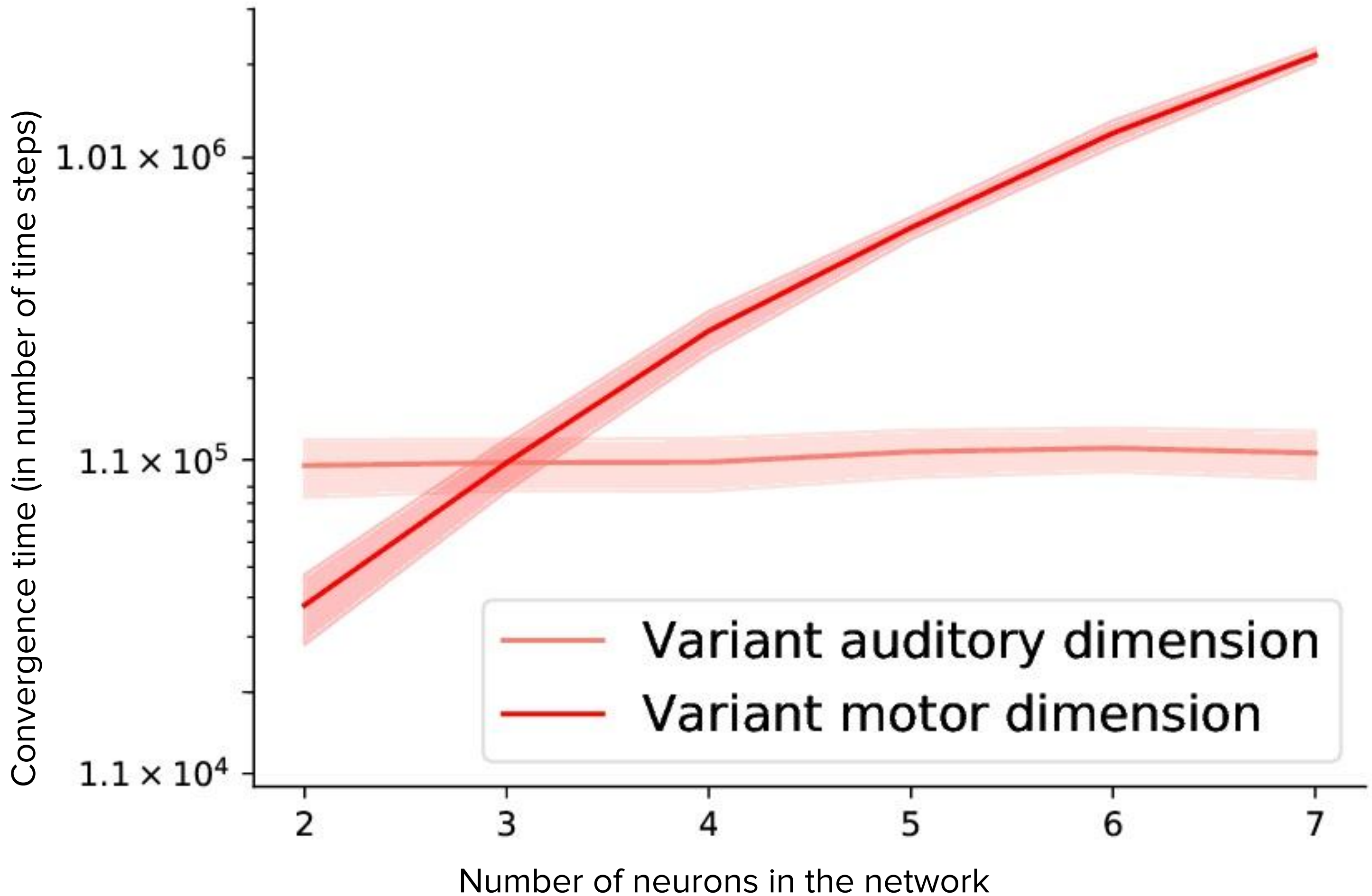


VARYING INPUT/OUTPUT DIMENSION



Distance from the motor target at convergence

VARYING INPUT/OUTPUT DIMENSION



Convergence time

SUMMARY

- Simple normalization schema are successful in the nonlinear model

- Decreasing tuning selectivity width:
  - convergence time explosion
  - accuracy of learning increases

- Auditory VS motor dimension

WHAT'S NEXT?

- Duration of syllable and feedback delay

WHAT'S NEXT?

- Duration of syllable and feedback delay
- Production of sound

WHAT'S NEXT?

- Duration of syllable and feedback delay
- Production of sound

Enjoy the poster from Xavier Hinaut

WHAT'S NEXT?

- Duration of syllable and feedback delay
- Production of sound
- Make prediction on experimental data

Enjoy the poster from Xavier Hinaut

Thanks for the attention.

$$d_t = \frac{||M^* - W_t A^*||}{n_m}$$